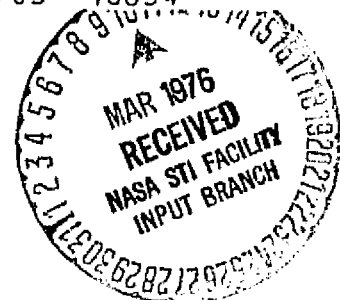


DESIGN DEFINITION STUDY
OF
NASA/NAVY LIFT/CRUISE FAN V/STOL AIRCRAFT

Supplemental Report - Technology Aircraft Risk Assessment

SEPTEMBER 1975

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Supplemental Report - Technology Aircraft
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Prepared under Contract No. NAS 2-6564 by
ROCKWELL INTERNATIONAL CORPORATION
Los Angeles, California
for
AMES RESEARCH CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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SUMMARY

This supplemental report contains the results of a study conducted in accordance with amendment 18 to National Aeronautics and Space Administration contract NAS 2-6564, to assess the risks associated with the Lift/Cruise Fan Technology V/STOL Aircraft program. Three candidate concepts for the technology aircraft design approach were considered in the study -- the low-speed-only modification, the full-performance modification, and the all-new aircraft concepts.

A total of 25 professional staff members participated in the identification and analysis of potential risk areas. The participants were representatives of the functional areas of aerodynamics, propulsion, propulsion-related advanced system design, flight control systems analysis, and program management. Sixteen items of potential technical risk were investigated. Summary analyses and a questionnaire survey were used to accomplish the risk assessment.

The survey results indicate that the lift/cruise fan technology aircraft program is feasible, from the standpoint of technical risk, with some evidence of uncertainty of meeting the planned schedule and relatively minor impact on estimated program costs.

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INTRODUCTION

A risk assessment study was conducted by Rockwell International Corporation, Los Angeles Aircraft Division, for the Lift/Cruise Fan Technology Aircraft program, under the provisions of Amendment Number Eighteen to the National Aeronautics and Space Administration Contract NAS 2-6564. The study was conducted during the period 27 May - 30 June 1975. This document describes the risk assessment and is submitted as a supplemental report to accompany the final report of the Part II studies authorized by the contract.

The study approach and structure were derived from the following set of objectives, extracted from the statement of work of the contract amendment noted above:

1. Evaluate the complexity relative to the state-of-the-art of each component, system, and interface to identify those components, systems, and interfaces where there could be a potential risk associated with the development of the Lift/Cruise Fan Technology Aircraft.
2. Evaluate the potential risk to achieve the performance goals and guidelines of Attachment I to the Statement of Work.
3. Assess the risk associated with the manufacturing and qualification testing of the components with potential risk identified in paragraph 1 above.
4. Assess the risks associated with the availability and delays in delivery of necessary materials and off-the-shelf components.
5. Determine the probable cost and schedule impact on each of the components, systems, or interfaces that are judged to have a potential risk of increasing cost or schedule in achieving an airworthy technology aircraft.

In a preliminary survey of the requirements of the planned technology aircraft development program, four technical areas were identified for further investigation to identify and define potential risks; these areas were aerodynamics, propulsion, propulsion-related systems design, and flight control systems. Key members of the technical staff in the primary disciplines involved were instructed to conduct a detailed review of their areas of responsibility relative to the lift/cruise fan technology aircraft studies, to identify components, systems and interfaces where potential risks could be foreseen in the technology aircraft development program. Three conceptual approaches, defined in previous phases of the overall

study, were considered in the further identification of risks, namely, (1) the low-speed-only modification of an existing aircraft, (2) the full-performance modification of an existing aircraft, and (3) the all-new aircraft design concept. Sixteen areas of potential risk were identified, based on the state of applicable technology in relation to the performance goals and guidelines of the technology aircraft development plan. The potential risk items are listed in Table I. From the technical staff and management elements of the Rockwell organization, 25 individuals were selected to participate in the technology aircraft risk assessment.

The risk assessment study was structured to include general technical analyses of the several potential risk items and a questionnaire-based opinion survey. The results are discussed in the sections which follow.

In addition to the technical feasibility and performance aspects of the risk items, specific questions were incorporated in the questionnaires relative to the risks associated with manufacturing and qualification testing (item 3 of the study objectives) as well as the risks associated with availability and delays in delivery of necessary materials and off-the-shelf components (item 4 of the study objectives). Also, technical evaluators were asked to comment on risk problems in these areas in their analyses of the various risk items. It is noteworthy that, in the majority opinion, materials, components, manufacturing and qualification testing were regarded as low-risk areas, although considerable emphasis was placed on the need for extensive development testing in a number of areas. Significant exceptions are noted in the conclusions section of this report.

IDENTIFICATION, DISCUSSION AND ANALYSIS OF POTENTIAL RISK AREAS

Item 1

VTOL Operation - Ground Proximity Effects

Operation in close proximity to the ground or landing surface potentially results in two undesirable effects. These are primarily related to loss of lift and hot gas reingestion. Loss of lift is a consequence of a suckdown effect, which is manifested in both reduced vehicle lift for a given level of fan thrust, and problems in attitude control. The hot gas reingestion that is associated with operation in ground effects tends to degrade both gas generator and fan performance by causing thermal distortion and local heating of the airflow. The ground effect of increasing fan back pressure must be considered and closeness to fan blade stall assessed. Development and test,

Table I
LIFT/CRUISE FAN TECHNOLOGY V/STOL AIRCRAFT

Potential Risk Areas

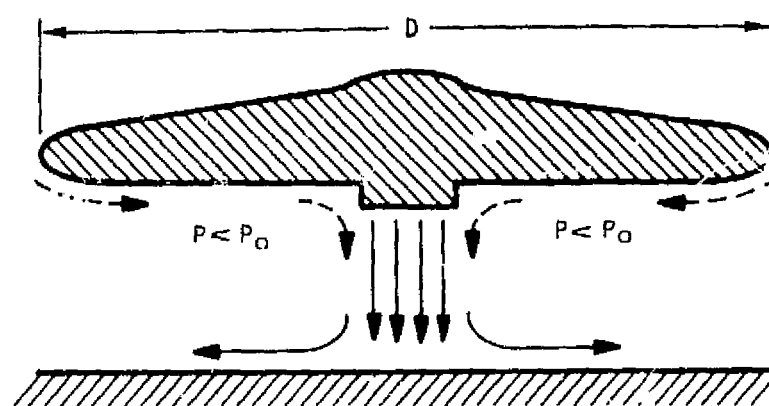
1. VTOL operation -- ground proximity effects
 2. STOL lift loss and handling characteristics
 3. High-speed drag
 4. Lift vector change with fan nozzle area
 5. Common gas generator exhaust plenum
 6. Fan distortion sensitivity
 7. Fan blade failure
 8. Hot gas ducting and valves
 9. Pitch nozzle design considerations
 10. Swivel nozzle design considerations
 11. Pitch nozzle heating
 12. Flight control system servo-actuator reliability
 13. Automatic hover control compensation system
 14. Flight control system controls and displays
- Fly-by-wire system
15. Aft gas generator inlet design

including a planned wind tunnel test program, are means of overcoming the risk in this technical area.

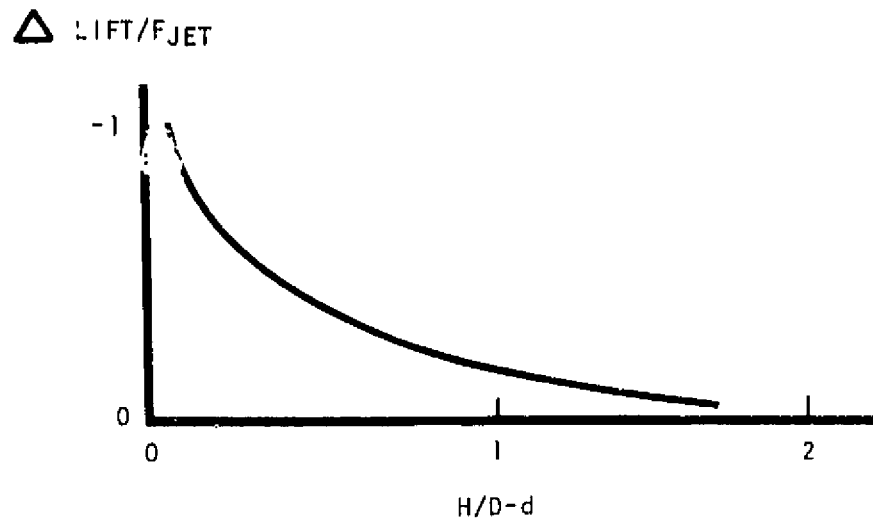
Analysis

The Technology Aircraft must demonstrate satisfactory VTOL performance with full controllability. The propulsive lift system consists of two J97 engines supplying gas power to two LCF459 tip-turbine lift/cruise fans plus a third J97 gas generator ducted to fore and aft pitch control nozzles. The fans will supply roll control power; yaw and directional control will be accomplished by fan nozzle thrust vectoring.

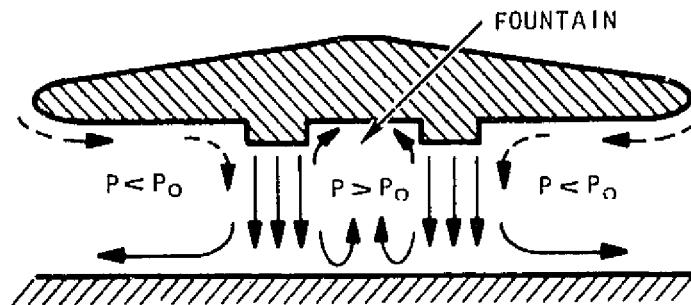
In general, jet lift systems are susceptible to suckdown in the vicinity of the ground, if the jet is located underneath and is relatively small in size compared to the bottom surface of the aircraft. As illustrated below, air inflow under the fuselage is induced by viscous entrainment with the lift jet stream.



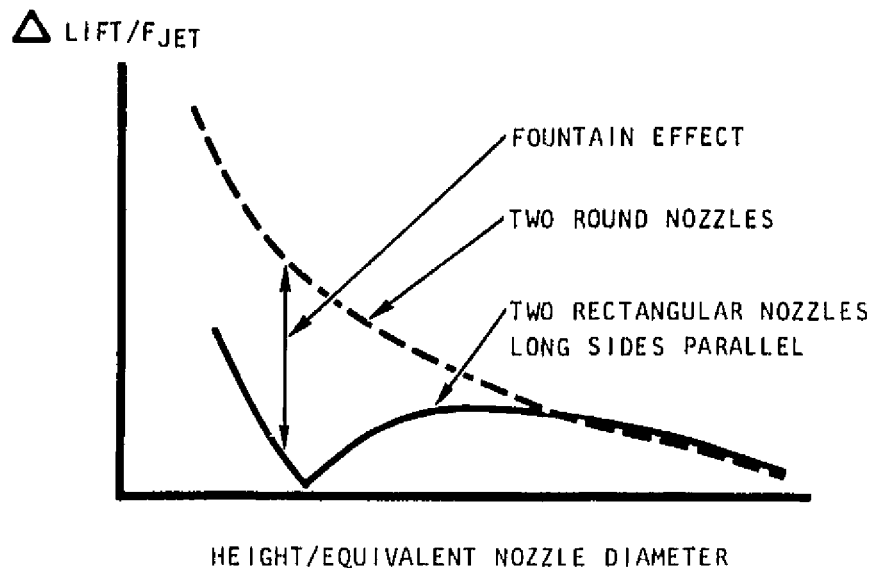
This suckdown effect is proportional to the proximity to the ground. AIAA 74-1167 has correlated the suckdown effect of single jets to a $\text{Lift}/F_{\text{jet}}$ vs $H/\bar{D} - d$, where \bar{D} is the equivalent diameter of the aircraft planform and d is the equivalent jet diameter.



However, multiple jets in proximity create a "fountain" effect (see below), which can partially cancel the suckdown.



This fountain effect is very configuration-sensitive, as illustrated by data from AIAA 74-1167.



Even with the benefit of the fountain effect, the suckdown effects of certain air vehicle configurations may still cause a significant reduction in air vehicle lift.

A water test basin is available at Rockwell International with the capability of assessing ground effects for specified air vehicle configurations to the first order of magnitude and also of assessing devices such as strakes to increase lift. The technology aircraft configuration and modifications thereto should be modeled and water-basin-tested to determine initial characteristics and establish what can be done to improve the lift.

Hot gas reingestion by gas generators and fans while in the proximity of the ground can cause significant thrust loss due to heating effects and, additionally, may cause gas generator stall due to excessive temperature distortion in the airflow entering the gas generator compressor. In the case of the technology aircraft, there is a risk possibility of reingestion of the forward pitch nozzle exhaust gases by the two forward gas generators. The degree of reingestion by these gas generators should be assessed as well as the degree of reingestion by the two fans. This can be done by the use of Rockwell International's water test facility in which water is used as a test medium and low-density pellets are exhausted from jet simulators into the water. A count of pellets collected in the simulated gas generator inlets

and fan inlets will indicate the portion of exhaust flow reingested by the gas generators and fans.

The Rockwell water basin facility will provide an inexpensive method for preliminary evaluation of air vehicle suckdown and reingestion effects. This type of testing should be supplemented by literature reviews and analytical studies to define the matrix of test variables required and the limitations of the use of water as a test medium. Also, this water basin testing should precede later ground proximity and low speed wind tunnel testing to be accomplished with a powered model using scaled tip-turbine fan simulators.

Item 2

STOL Lift Loss and Handling Characteristics

In the STOL operating mode the following types of problems contribute to potential performance risk:

- a. Induced lift loss due to power effects.
- b. Obtaining required maximum lift with the proposed configurations, because of uneven load distribution and high lift coefficients on the exposed wing panels.
- c. Large lateral-directional coupling at very low speeds, associated with high sideslip angles resulting from changes in wind direction and gusts.
- d. Wing-body-tail aerodynamic interaction.

Selective wind tunnel model testing is desired to evaluate and eliminate the risk in this technical area.

Analysis

The V/STOL Technology Aircraft will be required to demonstrate satisfactory lift capability and handling characteristics during the STOL mode of operation. Power effects in the STOL mode may result in an induced lift loss for air vehicle configurations with fan exhaust nozzle locations relative to the wing location similar to that for the proposed Technology Aircraft. Also, because of the very wide body, compared to the total wing span of the proposed aircraft configuration, it is considered that sufficiently accurate aerodynamic wing efficiency and maximum lift data are not available for use. The best estimating methods available indicate that there may be significant losses in both wing efficiency and maximum lift. Evaluation of wing characteristics is further complicated by the relatively large fan inlet flow

fields and uneven wing load distributions.

Potentially large lateral-directional coupling is of concern at very low airspeeds. This is caused in part by the extremely high sideslip angles resulting from changes in wind direction or gusts when the aircraft forward speed is small compared to the wind velocity. Characteristics of the wing-body-tail interactions, such as sidewash at the vertical tail, are difficult to assess analytically in the presence of power effects, high sideslip angles, and the unusually large relative body width.

Applicable data to evaluate the foregoing aerodynamic characteristics for the Technology Aircraft Configuration needs to be obtained since it is necessary to establish a data base before making estimates. It is considered that a more detailed aerodynamics literature search and study should be made to obtain available data, and that selective wind tunnel model tests should be conducted to verify certain aerodynamic characteristics and obtain data on other aerodynamic characteristics.

Item 3

High Speed Drag

The high ratio of body width to wing span increases the aerodynamic loading of the exposed wing panels and leads to high induced drag.

Considerable effort is needed to obtain desired supercritical airfoil characteristics for the all-new airframe configuration, including two-dimensional wind tunnel testing. In the absence of an adequate program for this purpose, it will be necessary to adapt an existing airfoil, with possible degradation in cruise characteristics.

High-speed drag considerations also include scrubbing drag of fan exhaust gas flow on the aircraft fuselage, as well as the effect of the change of the pressure field on the fuselage boattail in the presence of the exhaust gas flow.

Analysis

The full-performance and all-new aircraft configuration of the V/STOL Technology Aircraft are required to demonstrate satisfactory high speed cruise capability. The high ratio of body width to wing span for these Technology Aircraft configurations may cause a severe reduction in wing efficiency and result in high induced drag. It is expected that this will cause more severe drag penalties for the full-performance aircraft configuration with its higher sweep angle, shorter span, and smaller wing area.

It is considered that the supercritical airfoil characteristics assumed for the Technology Aircraft configurations can only be obtained by a relatively large effort involving a series of two dimensional wind tunnel tests. Current plans do not call for such extensive testing and an existing airfoil must then be adopted and modified resulting in cruise characteristics with M_{DD} values at least 0.02 less and lift values 20% less than previously assumed. High speed drag considerations also include the scrubbing drag of the fan exhaust gas flow on the aircraft fuselage, as well as the effect of the change of the pressure field on the fuselage boattail in the presence of the exhaust gas flow.

It is considered that a substantial risk is involved in meeting desired Technology Aircraft cruise performance levels with the use of an existing modified airfoil configuration. Therefore, adequate wind tunnel model testing should be conducted to obtain the necessary data for the desired supercritical airfoil configuration.

The wind tunnel program has been planned with the assumption that preceding applied research wind tunnel tests of the operational configuration and analytical efforts to define the Technology Aircraft configurations are sufficient to permit development of the Technology Aircraft with a minimum of wind tunnel configuration development effort. A potential risk exists to the program because of (1) the differences between the operational aircraft configuration and the Technology Aircraft configuration; and (2) the assurance that existing analytical methods can produce sufficiently accurate configuration data within the allocated resources has not been demonstrated on a prior aircraft development program.

Item 4

Lift Vector Change with Fan Nozzle Area

The variation in fan lift required for hover control may require a variation of fan nozzle area between 100 percent and 130 percent of the design value. If these nozzle area changes cause changes in the angle and location of the lift vector, aerodynamic and flight control interface problems will result. Further nozzle configuration definition and evaluation is necessary to insure satisfactory nozzle thrust characteristics.

Analysis

The low speed (LSM) V/STOL aircraft design does not include a variable area exhaust nozzle for the lift/cruise fan deflector system. Therefore, an energy transfer control system (ETCS) can only be used for the LSM aircraft unless the ground rules are modified.

The full performance aircraft design was proposed with a single swivel nozzle deflector system using the ETCS to provide the hover control. The exhaust nozzle of the low pressure ratio fan system will require an area reduction of approximately 20% to 30% from the design takeoff value to attain the desired performance during cruise conditions. The nozzle area change as the aircraft increases altitude and airspeed will not be rapid so as not to have much effect on aerodynamic or flight control characteristics. The ETCS operation during hover and low-speed conditions does not use nozzle area variation for thrust control. Performance loss of the swivel nozzle tested at NASA/Ames during increased vectoring angles will be investigated during a deflector performance improvement program submitted to NASA/Ames.

One anticipated method of performance improvement is to increase the nozzle throat area to prevent a reduction in exhaust flow rate during thrust vectoring. If a nozzle area increase is required to attain better performance when vectoring, the deflector system will be designed to provide zero or minimum changes in the angle and location of the lift vector.

For the concept, the required thrust response will be achieved by modulation of the fan exhaust nozzle during hover and low-speed conditions while thrust vectoring is being performed. This change might cause a slight shift in vector location and will need to be investigated to establish what the problem might be and how to provide control. At present, the problem does not appear to be a major part of the control system and might be solved by nozzle design or corrections to the control system hardware.

Item 5

Common Gas Generator Exhaust Plenum

Two gas generators exhausting into a common plenum chamber, as required by an Energy Transfer Control (ETC) system, must operate against a common static pressure. During a simultaneous throttle burst or commanded control excursions, the poorer engine could be back-pressured into a stall by the pressure gradient created by faster response in the better engine. Transient analyses of the gas generator/hot gas duct system plus appropriate gas generator control system modifications to maintain close speed synchronization of the gas generators are necessary to eliminate the risk in this technical area.

Analysis

The V/STOL Technology Aircraft will be required to demonstrate satisfactory hover control characteristics and capabilities. One hover control system being given serious consideration is the Energy Transfer Control (ETC) system to provide roll control. This system requires that two General Electric LCF459 turbo-tip lift/cruise fans be driven by the gas flow from two General Electric J97 gas generators which utilize a common hot gas duct system or plenum. The common exhaust plenum system is required so that during a control excursion, a portion of the gas flow from the opposite gas generator may be transferred through the interconnecting duct system to increase the thrust of the fan receiving the additional gas flow.

A problem may exist because the two gas generators exhausting into a common plenum must operate against a common static pressure. During a simultaneous throttle burst or a commanded control excursion, the poorer engine could be back-pressured into stall by the pressure gradient created by an above-average engine.

The extent and severity of this problem needs better definition for the particular propulsion system configuration used for the Technology Aircraft. During the aircraft technology development portion of the program, transient analyses of the gas generator/hot gas duct system should be performed in an attempt to define this problem and obtain a satisfactory solution. Consideration should be given to the incorporation of an isolation valve for independently starting the two gas generators, and for determining gas generator control system modifications which may be necessary to maintain close synchronization of the gas generator speeds during all modes of gas generator operation. The results of the above analyses should define the problem and permit a satisfactory solution to be made.

In general, operation of two gas generators on a common plenum system does not appear to be an insurmountable problem. Information from the General Electric Company pertinent to the operation of two or more gas generators exhausting into a common plenum duct system is as follows:

1. The performance of the combined system is established by the poorest engine in the group. For operation in a common plenum, all engines must operate at almost equal engine discharge pressures. For a

given pressure, a poor engine will require a higher exhaust gas temperature and fuel flow. If limiting operation is established by temperature or fuel flow, it is apparent that the better performing engines must be cut back.

2. Engine operation should be stable as long as engine speed unbalances are not too severe. For large numbers of engines, a simple throttle angle input type of control would probably not be adequate. A control system based on rotor speed, exhaust gas temperature and/or pressure will probably be required to maintain engine speed synchronization.
3. Once all engines have been started and somewhat synchronized, they can be valved into the common plenum. A higher than normal idle speed (like 70% speed) would be required to avoid hangup on accelerations due to slight mis-match of engines.
4. Operation of two General Electric J97 gas generators into a common manifold has been demonstrated.

Also, the McDonnell Douglas Company has successfully demonstrated the operation of two General Electric J97 gas generators on a common exhaust duct system. An experimental investigation of a specific propulsion system configuration designed to explore the energy transfer control (ETC) system characteristics was conducted. In general, there was no problem with the operation of the McDonnell Douglas configuration with the gas generator speed mis-match restricted to 1% to 2%. Additionally, there was an indication that a considerable gas generator speed mis-match was required to stall the gas generator with the lower speed. Although the results of these tests were encouraging, it is considered mandatory to further explore the characteristics of the ETC system for a specific propulsion system configuration in which hot gas duct lengths and volumes are appreciably different than those for the McDonnell Douglas test configuration.

Item 6

Fan Distortion Sensitivity

Fan stalls due to distortion can occur from hot gas ingestion during VTOL operation, rapid attitude changes during STOL operation, and high angle-of-attack maneuvers during cruise. Tip-turbine fans are less sensitive to

distortion than conventional front fan engines, but quantitative differences are not readily available. Conservative design techniques to prevent fan stall may lead to longer-than-necessary fan inlets and exhaust systems that will force detrimental air vehicle weight and performance effects. Testing of different length inlet models with appropriate forebody in a low-speed wind tunnel is needed to obtain appropriate distortion data. Additionally, full scale distortion testing of the selected inlet-fan-exhaust system is necessary to verify acceptable distortion characteristics.

Analysis

The V/STOL Technology Aircraft will be required to operate with attitude changes and possible hot gas ingestion conditions during the VTOL mode, with rapid attitude changes during the STOL mode, and high angle-of attack maneuvering during the cruise mode. These operating conditions are conducive to fan inlet duct flow separation and/or conditions resulting in increased fan inlet distortion. Additionally, the specific fan exhaust system configuration will cause a certain degree of distortion in the flow downstream of the fan, which will influence the fan inlet distortion characteristics. Increased exhaust flow distortion is particularly expected with the fan exhaust nozzle in highly vectored positions during the VTOL mode.

A problem may exist because fan stall may occur if the fan distortion levels become sufficiently high. Conservative design techniques to prevent fan stall for both the inlet duct and exhaust duct configurations may result in a longer-than-necessary fan inlet and exhaust system. This may dictate an inlet location that severely restricts pilot vision, increases air vehicle weight, and/or causes detrimental performance effects.

Fan distortion characteristics and limitations need to be defined by General Electric for the selected LCF459 lift/cruise fan design. Such data are expected to be forthcoming during the development of the fan configuration, and are required for correlation with both inlet model and full-scale inlet test data. During the aircraft technology development portion of the program, testing of different length inlet models with appropriate forebody in a low-speed wind tunnel should be conducted to obtain distortion data as a function of inlet configuration, angle-of-attack, and angle-of-yaw. These data will be used to aid in the selection of the inlet configuration.

Later, full-scale distortion testing of the selected inlet-fan-exhaust system should be performed in a large-scale wind tunnel to verify acceptable distortion characteristics.

In general, it is expected that the remotely located tip-turbine driven fan will not be very sensitive to distortion. Earlier fan configurations have been designed to withstand considerable inlet distortion due to cross

flow effects when installed in an unrestricted shallow inlet appropriate for lift fan installations. Information from General Electric indicates that the General Electric LCF459 turbotip fan, which is to be developed for the V/STOL Technology Aircraft, is expected to have distortion characteristics which are as good as, or better than, previous lift fan designs. During the VTOL mode of operation, it is intended for the LCF459 fan to operate with an increased exit area to provide a higher stall margin. With this type of operation, the fan stall margin is expected to be about 25-27%. Although the distortion characteristics of the new LCF459 fan design are expected to be satisfactory for lift/cruise type installations, it is considered mandatory to verify the distortion characteristics of the selected inlet-fan-exhaust system through full-scale testing.

Item 7

Fan Blade Failure

Even though the fans are designed to withstand foreign object damage, experience with turbofan aircraft has shown that fan failures have occurred on occasion. An assessment of the potential risk of the selected lift/cruise fan configuration to catastrophic structural failure as a result of fan blade failure should be made and the potential weight penalty (if any) to maintain structural integrity should be identified.

Analysis

The two tip turbine fans provide the primary aircraft thrust during the vertical and horizontal flight modes. Any depreciation of fan efficiency can cause a commensurate loss of thrust which, if incurred during critical portions of the vertical or vertical/horizontal transition flight modes, can have major effects on aircraft controllability. Such effects can range from minor thrust loss, which can be countered by trimming the healthy opposite-side engine, to major or complete thrust loss requiring immediate shutdown of the opposite side engine to minimize the resulting violent roll or yaw reaction.

Design of the tip turbine fan engine to withstand normally encountered foreign object damage (i.e., bird and ice ingestion) is the province of the engine manufacturer as is the design of blades to minimize the problem of fatigue failures.

The likelihood that either of these types of failures will occur, and the possible catastrophic effects on the subject aircraft, requires the aircraft manufacturer to monitor closely the engine design in the critical areas

to utilize design and operative techniques to prevent externally and internally generated foreign object damage and to incorporate warning devices and operating methods to counter the effects of fan blade failures. Risks are further discussed below.

A. Causes of Failure

- (1) FOD - Damage to one or more fan blades due to entry of foreign objects into the fan inlet duct. This damage can originate externally from bird ingestion, from wheel thrown objects, from objects entrained by inlet generated vortices, or internally from debris caused by breakaway of aircraft components in the inlet airstream.

Damage to the tip turbine blades can result from debris generated within the aircraft hot gas duct system.

- (2) Fatigue - Structural failure of the blade or blade retention device can cause separation of all or part of the effected blade and consequent damage to adjacent blades.

B. Effects of Blade Failure

- (1) Distortion of the fan or turbine blade contours will result in diminished blade efficiency and reduced pumping or driving capability. The resulting fan thrust loss will depend upon the magnitude of the damage. In any event, the aircraft will experience an asymmetric thrust following the blade failure.
- (2) Blade structural failure will result in structural damage to the fan case, nozzle and scroll and adjacent aircraft components in the radial path of the blade trajectory. Approximately one-third of the fan periphery at the blade station is adjacent to aircraft primary structure and components.

The imbalance condition caused by the failed blade or blades will result in major vibration effects on the fan structure, the fan mounting system and the supporting aircraft structure.

C. Failure Indication

- (1) Depreciation of fan or turbine blade efficiency due to blade damage will be indicated by changes in fan RPM and evidence of a roll or yaw condition due to the resulting asymmetric thrust.

Blade failures will be indicated by high vibration of the affected fan or by physical damage to the aircraft structure caused by the exiting failed blades.

- D. To minimize the risk to the program by loss of the aircraft due to the subject failures, it will be necessary to employ rigorous methods in design of the fan blades and in measures to prevent foreign object damage. In addition, it will be necessary to install warning devices to alert the pilot to a failure condition or automatic devices to initiate corrective action where the failure would cause immediate and drastic aircraft control reactions.

E. Cost and Schedule Impact

The cost for added fan blade design capability is unknown and the question should be addressed to the engine manufacturer. The cost of design to minimize the potential for foreign object damage should be within the present budget.

Definition, design and development of the above features will not impact the present schedule.

Item 8

Hot Gas Ducting and Valves

Hot gas ducting failures may be caused by fatigue, gas generator hammer shock pressures, or implosion during propulsion control transients. The hot gas valving may crack or break, seize, or bind up to eliminate response to the design power supply. These and other failure modes can cause critical fan and pitch nozzle thrust loss, overheating in the ducts, and air vehicle structural damage due to overheating or overpressurizing of air vehicle compartments. It is necessary to evaluate the hot gas cycle and burst pressure requirements, thermal degradation of duct insulation, allowable leakage, effects of internal flow resonances, and vibration limitations of the hot gas system.

Directly related to the above, and an integral part of the hot gas ducting considerations, is the matter of duct/valving insulation concepts and compartment temperatures. The weight, cost, and development-time penalties which may be incurred in meeting program objectives must be evaluated from the standpoint of the risks involved.

Analysis

Hot gas duct and valve systems that must operate in a 1600°F temperature and random vibration environment, and provide rapid response, are within the advanced state-of-the-art regime, and as such, present the following problem areas:

a. Hot Gas Ducts:

- ° Combined high/low temperature cyclic fatigue failure.
- ° High temperature creep and stress rupture failure.
- ° Hammershock pressures due to fan failures or rapid valve closing.
- ° Pressure reversals due to rapid gas generator shut-down.
- ° Untuned support system that does not consider thermal expansions, vibration, inertia, and structure elasticity.
- ° Degradation of thermal and sealing systems.

b. Hot Gas Duct Valves:

- ° Rapid operating response rates.
- ° Dynamic springback through the power system.
- ° Additional problems as (a) above.

The hot gas ducts failures can cause

- ° Excessive buckling.
- ° Hot gas leakage.
- ° Fragmentation due to duct explosions.
- ° Duct system collapse due to implosion.
- ° Primary structural damage.
- ° Equipment damage.
- ° Fan and pitch nozzle thrust losses.

The hot gas duct valve failures can cause:

- ° Inadequate or no power supply response.
- ° Valves seizing-up.
- ° Cracking or breaking.
- ° Loss of system.
- ° Excessive hot gas bypass leakage.
- ° Gas generators, fans and nozzles damage.

Each of the problem areas noted above must be analyzed individually and in combination to determine their magnitude. To supplement these analytical methods, testing will be required. The following are a few of the major tests required in order to assist towards a resolution:

- ° Thermal life-cycle pressure test(s).
- ° Leakage rate test(s).
- ° Thermal degradation test(s).
- ° Thermal/pressure/vibration variables test(s).

During the last several years Rockwell/LAAD has supported an IR&D program to develop an advanced state-of-the-art hot gas duct system. Although this program represented a relatively modest level of effort, an innovative new duct system, in part, has been conceived, developed, and tested using a J-97 gas generator. In the course of this work Rockwell/LAAD has established a degree of proficiency in this high risk area and has the capability to deal with problems in this area of technical risk. A brief review of the state-of-the-art in hot gas ducting systems is provided below. Figure 1 depicts the typical operating conditions.

1. Ducting

Straight sections of a (proprietary) lightweight/low expansion ducting system concept have been designed, fabricated, and thermally tested by Rockwell/LAAD with promising results with an engine exhaust gas temperature of 1375°F. At least one more design/fabrication/test (this time including vibration tests) iteration would be required to complete the development of this system and provide the confidence level required for use on the Technology Aircraft or the Multimission Aircraft. This ducting system has been shown to be an improvement over the conventional external insulation system from both a weight and cost standpoint.

Lightweight/low expansion duct systems, such as the Rockwell/LAAD concept, apparently have not been developed for special shapes such as bend and non-round sections. Although some lightweight systems have been developed, it is not known if the thermal requirements of this application can be met.

2. Valves (large)

Valves for aircraft usage apparently have not been developed for the 1400-1600°F temperature range.

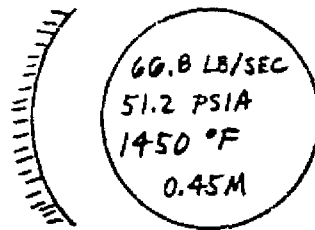
3. Bellows and Joints

Bellows and joints also apparently have not been developed for the above temperature range.

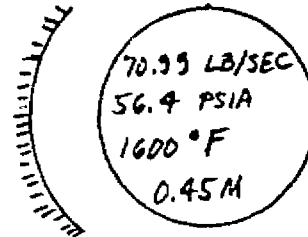
DUCT OPERATING CONDITIONS

NORMAL

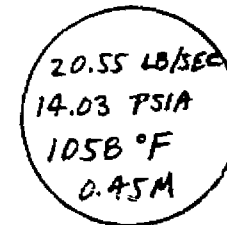
MAX STEADY STATE
(2 CYCLES / FLT)
(1 MIN / CYCLE)



MAX CONTROL EXCURSION
(3 SEC MAX / EVENT)
(EVENTS / CYCLE)

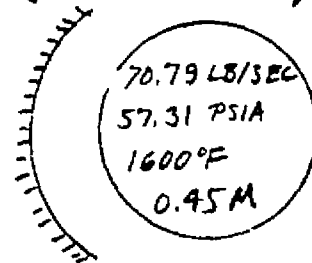


NOMINAL CRUISE
(5 HRS / FLT)
(45 HRS / MO)



EMERGENCY

MAX STEADY STATE (WATER INJECTION)
(1 PER LIFE)
(2 MIN DURATION)



Item 9

Pitch Nozzle Design Considerations

The operating area variation limits and operating conditions must be defined for the pitch nozzles, along with mechanization requirements. Potential risk exists in the design of mechanizations to meet performance requirements within the operating limits and conditions. Both VTOL and STOL modes should be analyzed.

Analysis

In both the VTOL and STOL modes the pitch nozzles must be variable in exit throat areas to provide the thrust variations required for the operational conditions. These must operate with a rapid response rate, controlling high temperature gas. The risk exists in the design of the mechanisms to operate these variable pitch nozzle areas in order to meet the performance requirements.

The nozzle operating area variations, response rates, temperatures and loads requirements for both the VTOL and STOL missions must be defined in order to design and analyze the necessary mechanism. Several mechanical system tests will be performed to supplement the design task resolution.

Item 10

Swivel Nozzle Design Considerations

For VTOL, STOL and cruise conditions, the lift/cruise fan swivelling nozzles will be required to operate over design-established ranges of area variation and angular travel. Mechanizations to provide the required area variation and travel of the nozzles, and related features of the energy-transfer-control (ETC) should be analyzed to evaluate potential risks.

PRECEDING PAGE CORRECTED AND FILMED

Analysis

In the VTOL, STOL, and cruise modes the swivel nozzles must have controlled rotation combined with variable nozzle exit areas to provide the vectored thrust required for the operating conditions, when the energy-transfer-control (ETC) systems are considered. These must operate with a response rate adequate to control the fan flow.

Some risk may exist in the design of the mechanisms that will integrate the swivelling and area variation features of the nozzles in order to meet the performance requirements.

The integrated swivel and area variations, response rates, temperatures, and loads requirements for the VTOL, STOL, and cruise missions will be defined in order to design and analyze the necessary mechanism. Several mechanical system tests will be performed to supplement the design task resolution.

Item 11

Pitch Nozzle Heating

In both VTOL and STOL operation, the hot gas flow from the pitch nozzles creates a high-temperature environment in the surrounding areas. In emergency VTOL operation, the transient temperature can reach 1600°F. There is a potential risk of excessive heating of landing gear, tires, and/or adjacent airframe structure. An analysis of the impact of this condition, action possible to eliminate the problem, and evaluation of the risks involved, should be accomplished.

Analysis

Pitch control in hover operations, and a fraction of the jet lift, will be supplied by fore and aft pitch nozzles utilizing exhaust gas from the

third gas generator. During design operation this gas generator will be run at design speeds, but the pitch nozzles will be deliberately opened to depress the operating line and reduce the thrust to about 50 percent of that at Intermediate Power and the pitch nozzle exhaust temperature to 620° Kelvin. However, during emergencies involving a loss of lift, the third gas generator may be operating at full power with pitch nozzle gas temperatures above 1000° Kelvin. The forward pitch nozzle is located just forward of the nose wheel and the tires can withstand such temperatures for only transient durations without damage.

The pitch nozzles must be closed during normal flight to minimize wind-milling and drag of the inoperative third gas generator. This full closure requirement may dictate a rectangular nozzle design or some nozzle closure device. Cold flow tests of downwash suppression nozzles reported in NASA TN D-2263 showed that rectangular nozzles with aspect ratios above 2 have excellent wake suppression normal to the short side of the nozzle. Jet wake estimates are available for the YJ101 engine, these data were dimensionally scaled to the forward pitch nozzle utilizing flow equivalent to 1/3 of the YJ101 gas flow. A rectangular pitch nozzle wake was computed using a ratio of the NASA cold jet dynamic pressure decay vs jet distance to the hot jet dynamic pressure patterns calculated from YJ101 temperature and velocity profile estimates. These calculations showed an unacceptable tire thermal environment with a circular nozzle, but acceptable jet temperature decay could be achieved with the rectangular nozzles evaluated in the subject report. It is concluded that the risk of nose wheel tire overheating can be eliminated through the use of pitch nozzle geometries evaluated in NASA TN-D-2263.

Item 12

Flight Control System Servo-Actuators Reliability

To meet the reliability requirements of the actuation system for safety-of-flight items requires the use of triply redundant electrohydraulic servo-actuators on the technology aircraft. The cost of development of integral triple redundant servo actuators or the use of force-summed servos should be investigated in light of overall allowed system cost.

Analysis

The redundancy concept for the Lift/Cruise Fan Technology Aircraft is that no single subsystem failure should cause loss of the aircraft. This statement implies that a certain amount of redundancy is required. The required redundancy is dependent upon the number of subsystem failures that are allowed before loss of the aircraft is "acceptable".

The proposed "acceptability" level is that after one failure, the subsystem shall continue to operate. While a second failure does not require operation of the subsystem, the second failure should not cause loss of the aircraft. This type of operation, fail-operate-failsafe, requires triply-redundant control paths for all safety of flight items. To meet this requirement triply redundant electro-hydraulic servo actuators are required to power the pitch control aerodynamic surfaces, the lift/cruise fan nozzles, and the pitch control hot gas nozzles.

If the development time or money is excessive, as related to the technology aircraft schedule and funding, alternate methods of providing the required redundancy are available. The use of three separate electro-hydraulic servo actuators attached to the designated surfaces or valves provides the required redundancy. The design of the mounting structure and the failure detection and actuation system is a design problem that is not directly part of the integral, triply redundant, servo actuator installation. Another "work around" would be to use two dual-redundant servo actuators. This technique could give more redundancy than required but in its simplest form gives fail operate - failsafe operation. The failsafe servo concept for the dual redundant servo is shown in figure 3.

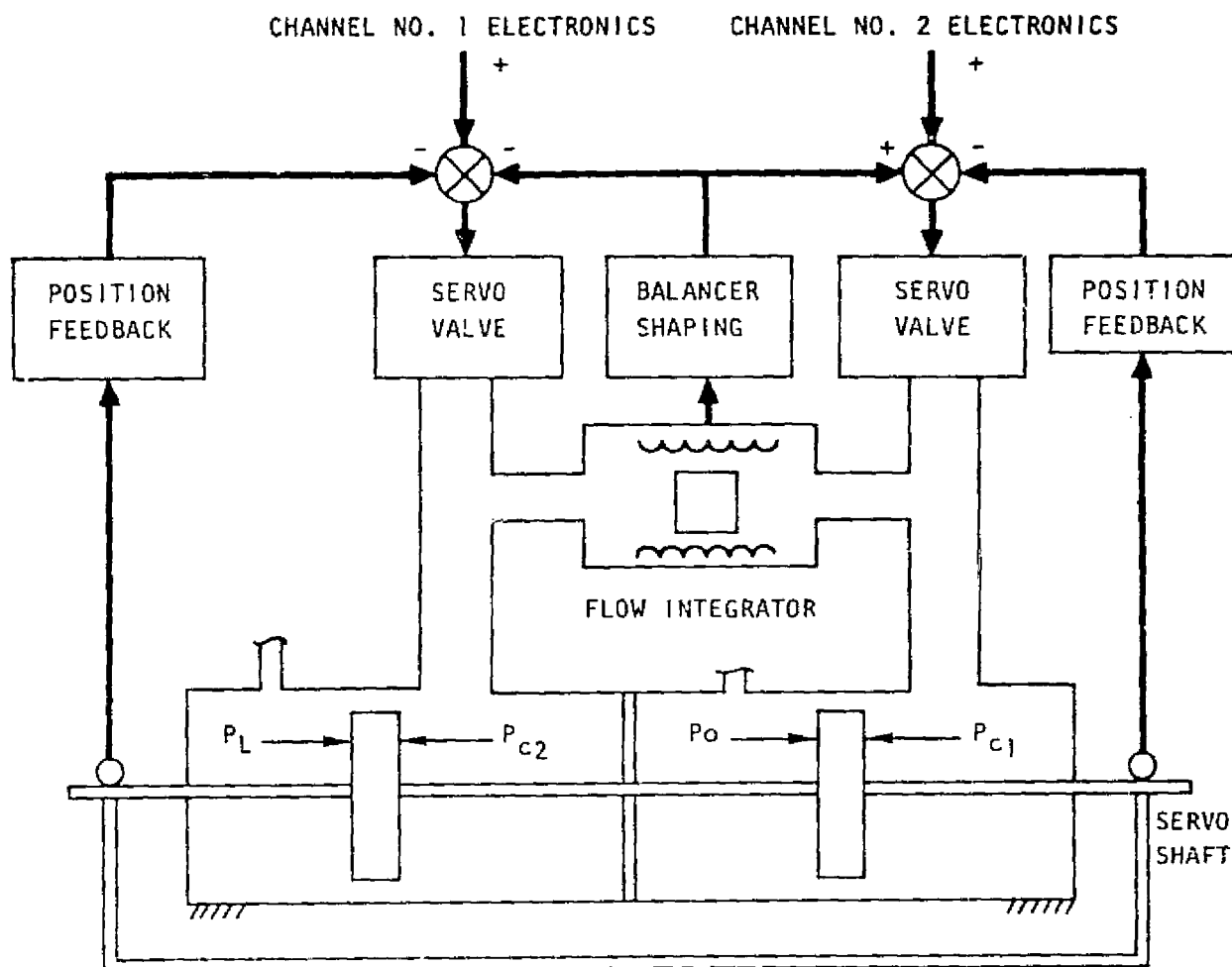
The basic technology required for triply redundant electro-hydraulic servo actuators does exist. No major breakthrough in metals, electronics, or hydraulics is required. The risk is in the item presently being a research item. No manufacturer carries "off-the-shelf" triply redundant electro-hydraulic servo actuators.

Upon receipt of actuator performance requirements, subcontractors can prepare cost and schedule data. If these cost and schedule data do not fall within the allotted program guidelines, the workaround methods can be employed.

Item 13

Automatic STOVL Hover Control Compensation System

During the hover mode, when the pilot workload is the greatest, a propulsion system failure can conceivably cause the loss of the aircraft. The risk of aircraft loss can be reduced by the incorporation of an automatic compensation system. By monitoring the propulsion system parameters, the necessary propulsion and vehicle attitude corrections can be made faster automatically than manually, which could save the aircraft. A study and evaluation of an appropriate automatic compensation system should be made.



INCREMENTAL SHAFT DISPLACEMENT DUE TO SIGNAL IN ONE CHANNEL ONLY CAUSES MAXIMUM OPPOSING FORCE IN OTHER CHANNEL BECAUSE OF HIGH GAIN POSITION FEEDBACK. BALANCER EQUALIZES VALVE SIGNALS AT CONTROLLED RATE, RESULTING IN SAFE TRANSIENTS DUE TO ANY FAILURE.

P_c = VALVE CHAMBER PRESS

P_o = RETURN PRESS

P_L = LINE PRESS

Analysis

The most critical time for a propulsion system failure is during the hover or powered lift portion of the flight. At this time the pilot workload is the greatest, since the aircraft is approaching the ground at what could be called "controlled crash conditions". At this time a propulsion system failure without very rapid corrective action will cause loss of the aircraft.

If one of the two gas generators feeding the lift/cruise fan fails, the thrust will be asymmetrical causing a large rolling moment. The flow from the one gas generator must be made symmetric, a portion of the gas from the pitch control gas generator must be diverted into the lift/cruise fan duct, and vehicle attitude requirements must be maintained. If the gas generator feeding the pitch control nozzles fails, some gas from the lift/cruise fan system must be diverted to provide pitch control.

All these corrections, if done manually, take valuable time when the pilot's attention is needed to make the landing. To aid the pilot in determining what is happening so that he can take corrective action, instruments and indicators beyond the normal flight instruments must be provided to show the failure, and what automatic corrective action is being taken.

By monitoring the propulsion system parameters to give the indication of failure, the FBW computer can be programmed to determine the existence of a failure and, depending upon the condition of the aircraft, altitude, weight, velocity, etc., take corrective action and/or present alternatives. The corrective action could be to return to aerodynamic flight, or to readjust the gas flow so that the V/STOL landing can be continued.

The use of simulation to solve problems is an established science. By using digital computers to simulate the aircraft and failure modes, automatic and/or manual corrective techniques can be synthesized. After these techniques are synthesized they will be mechanized on a six-degree-of-freedom moving base simulator to test them out with a pilot in the loop.

The risk of a propulsion system failure always exists. The risk of aircraft loss due to a propulsion system failure can be reduced if corrective techniques can be thought out beforehand. At hover or powered lift altitudes and velocities, the time to take corrective action is less than at 30,000 feet and 0.6 Mach; therefore, automatic and/or manual corrective techniques during the hover mode are mandatory.

Item 14

Flight Control System -- Controls and Displays

The three-axis control of V/STOL aircraft in the critical steep takeoff and landing profiles used for optimum performance, and the trim changes inherent in transition, require split-second timing and the time-varying adjustment of control forces. The quickness of control action is particularly important in the event of a failure. There is a potential risk in defining the proper automatic control system and displays to assist the pilot with these control problems and in ensuring its reliable operation in all of the potential normal and emergency modes of operation.

Analysis

During V/STOL takeoff, landing and transition the pilot must maintain three axis control of the aircraft, manage engine thrust levels and control the direction of the total vehicle thrust vector. In order to accomplish these tasks suitable controls and displays must be available to the pilot to enable and assure him that he is accomplishing his flight tasks.

Using the science of simulation will prove out the controls and display arrangement for the Technology Aircraft. By using a six degree-of-freedom moving base simulator, the research pilots can get a "feel" for the handling qualities of the real aircraft. Additionally, the location of the displays and controls can be verified for ease of viewing and handling.

An illustration of the above techniques is given in Lift Fan V/STOL Research Transport Flight Simulation. Figure 4, on the following page, is a copy of a figure from the report. In figure 4, the relationship between tasks 14 and 15 illustrate the point. Task 14 did not

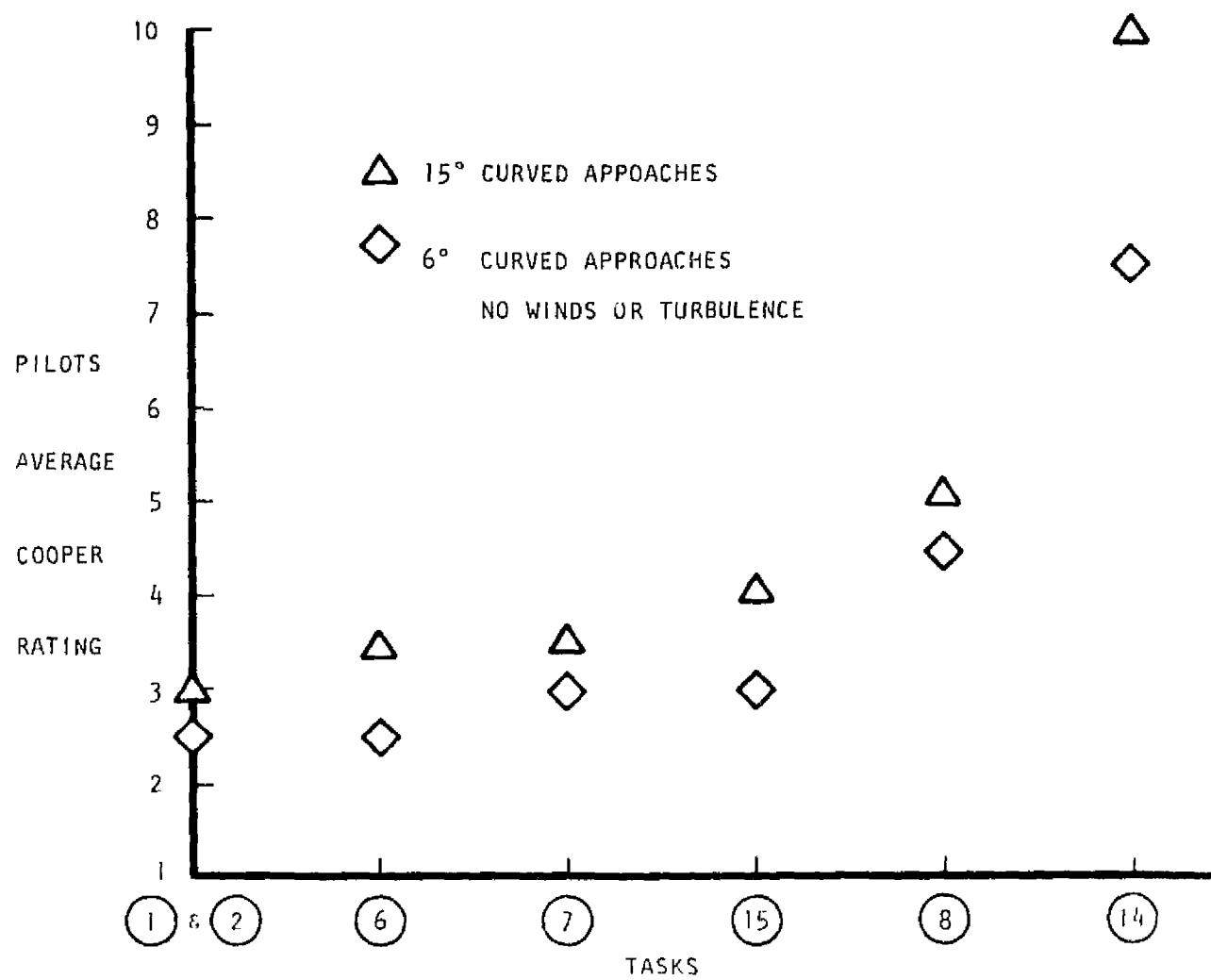


Figure 4. Landing Approach Pilot Rating Summary

have a mechanized control. The pilot had direct control over the Lift/Cruise fan thrust angle, and the engine throttles separately. In Task 15 these two commands were integrated into an h lever and v wheel. The resultant improvement in pilot opinion is drastic, from major deficiencies to minor but annoying deficiencies.

The installation of controls and displays, especially those that relate to the V/STOL mode of operation without man-in-the-loop simulation, could lead to objectionable criticism of the Technology Aircraft that would have to be corrected by expensive and time consuming modifications during the flight test program.

Item 15

Fly-By-Wire System

A fly-by-wire (FBW) flight control system is planned for the technology aircraft. Operating experience with FBW is limited, and application to V/STOL aircraft thus far consists only of pre-flight development. While it is understood that various items of hardware are available from suppliers for use in FBW systems, it is believed that the major problems in V/STOL application lie in the design and integration of the complete system, rather than in specific hardware items. Hence FBW is considered to be a potential risk in the technology aircraft program.

Analysis

In the context of this study, fly-by-wire is considered to be from the sensor or transducer output to actuation command input. Sensors and transducers are not considered risk items since they have been used in many production aircraft programs. The actuation system is considered a risk and is discussed under the item pertaining to servo-actuator reliability (item 12).

Fly-by-wire flight control systems are anticipated to be used in future aircraft to reduce weight and increase reliability and performance over mechanical systems. Specific items in the FBW system are not considered risks. Analog-to-digital and digital-to-analog converters have been used previously. Airborne digital computers have been used since the start of the missile age. The integration of these and all other components into a satisfactory workable system is a risk.

The use of simulation will be the major tool to integrate all the FBW system components into a flyable system. As hardware and software become available these components will be incorporated into the simulation program replacing their "ideal" models. This way their effect on an ideal flight control system can be analyzed and corrections, if required, made. The knowledge that is being gained and disseminated in other FBW systems currently flying and under development, will lower the risk for this item.

Item 16

AFT Gas Generator Air Inlet Design

The aft, or third, gas generator normally provides gas flow to the pitch nozzles during the STOVL operating mode. During the high speed, low altitude dash envisioned for the operational aircraft combat search and rescue mission, this gas generator is also employed to provide additional thrust by operating as a turbojet engine. This gas generator is located in the upper aft fuselage in a backward-facing engine/inlet installation. Although the backward facing inlet may provide adequate performance during the STOVL mode, its performance may be poor in the dash mode when the turbojet thrust augmentation is desired. Different backward facing inlet model configurations should be tested in order to determine a suitable inlet arrangement for the aft gas generator installation.

Analysis

The aft, or third, gas generator powers the pitch nozzles in the STOVL mode and can be used as a backup gas generator for the lift/cruise fans. This gas generator is also employed for thrust augmentation during the high speed, low altitude, dash envisioned for the combat search and rescue mission. The gas generator is reversed to favor the VTOL operation with the inlet positioned behind the gas generator to direct the exhaust forward toward the exhaust duct manifolds. The air inlet consists of a series of louvers opening to a plenum chamber. These louvers are closed during normal horizontal flight operation. The plenum chamber can be made sufficiently large, with turning vanes to direct the airflow toward the compressor inlet, such that acceptable distortion and pressure recoveries of 96-98 percent can be realized in STOVL operation. However, at flight Mach numbers of 0.7-0.8 this inlet will be operating in an upper fuselage boundary layer several inches thick and attempting to turn this boundary layer airflow through 180 degrees, see figure 5. The inlet pressure recovery will be on the order of 65-70 percent, reference NASA MEMO 12-21 58L. The resulting gas generator thrust will be about 40-50 percent of the potential thrust of this power plant. The design Sea Level dash speed of the weapons system may not be achieved.

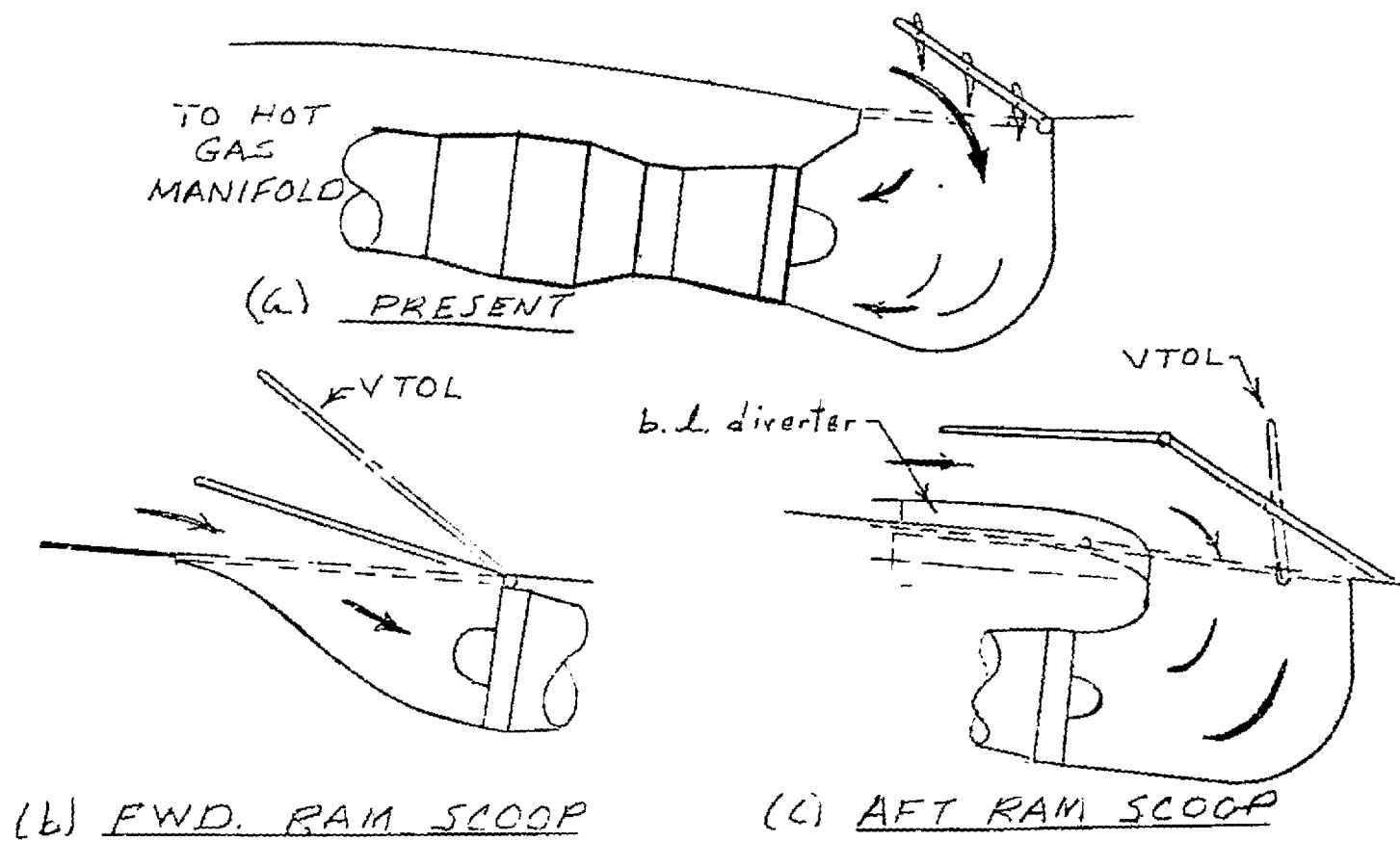


Figure 5. Mt Gas Generator Inlet

The risk to the Technology Airplane is confined to the full demonstration of the operational air vehicle capability. The inlet shown on the airplane drawings will be satisfactory for VTOL flight demonstrations. However, in the present configuration the low level high speed engine thrust may be disappointing.

Rotating the gas generator 180 degrees and designing a ram scoop inlet for high speed flight, figure 5b, may increase the inlet pressure recovery by 10-15 percent at high speed with a negligible impact on inlet recovery during VTOL operation. The gas generator exhaust would then be turned 180 degrees toward the forward exhaust gas manifold and with a 2-4 percent pressure loss in all operations. Alternatively, figure 5c, an aft ram scoop with a 180 degree turning of the gas generator air could be employed. This inlet would need a boundary layer diverter to remove the lowest energy portion of the boundary layer in order to prevent flow separation at the inner sector of the 180-degree turn. A rotating flap in the inlet door will be needed to increase the inlet area for VTOL operation. It will also be necessary to retract the boundary layer diverter into the fuselage for 99+ percent of the horizontal flight time. It should be possible to achieve a 75-80 percent pressure recovery at $M_0 = 0.8$ with this inlet.

The risk is minor if a Sea Level Dash speed below 0.8 Mach number is accepted. The figure 5a configuration is the least expensive and the air vehicle may be capable of $M = 0.8$ with this inlet. The figure 5b inlet is a moderately low risk design but may require some vortex generator development. However, the 180-degree bend in the exhaust duct will cost 1-2 percent thrust from the third gas generator. The figure 5c inlet is very complicated, and will require appreciable aircraft volume for stowage of the boundary layer diverter. This inlet is not cost-effective.

QUESTIONNAIRE SURVEY

Procedures

In preparing the questionnaire format, consideration was given to each of the points contained in the statement of work of the contract amendment. The draft questionnaire was distributed to each of the key members of the technical disciplines concerned - Aerodynamics, Propulsion, Advanced Systems Design, and Flight Control Systems Analysis - for comment and suggested revision.

All of the 25 participating evaluators in the risk assessment study were provided with questionnaire forms. Each of them submitted at least one questionnaire, and on the average each person submitted 2.8. All of

these were analyzed, with the exception of two which were set aside because they were based on the suggested implementation of a very extensive wind tunnel test program, beyond the expected scope of the total program. The remaining questionnaires numbered 67.

In general, the 16 potential risk areas identified in the study were adequately covered by competent and proficient people in the several disciplines. An overall average of 4.2 responses per risk item were received. The effective average was greater, because of circumstances surrounding the last two items of identified risk. These two (Fly-by-wire flight control system and aft gas generator air inlet design) were added near the end of the survey, with insufficient time remaining for an added cycle in the questionnaire solicitation, but appeared to be of sufficient importance to warrant review. Each of these items was covered by two questionnaires only.

Survey Findings

There was a substantial pattern of uniformity in the majority of the questionnaires submitted. This does not mean that the evaluators were unanimous in their opinions, but there were pronounced groupings of answers to all of the qualitative questions. Despite the fact that the particular risk items identified were retained "on the list" through successive discussions, and notwithstanding the strong note of concern in some of the rhetorical analyses, the questionnaires, on balance, reflected a very favorable outlook for undertaking the development of the V/STOL technology aircraft. In general, there were no collective responses which would indicate high risk in achieving the performance goals and operating characteristics desired in the technology aircraft. Areas in which certain individual evaluators did indicate their beliefs of very high risk were:

Item 1	V/TOL Operation - Ground Proximity Effects
Item 3	High-Speed Drag
Item 8	Hot Gas Ducting and Valves

In each of two other cases, one individual saw very high risk in the development and functional effectiveness of equipment. These were:

Item 13	Automatic Hover Control Compensation System
Item 14	FCS Controls and Displays

The two late add-on items - fly-by-wire flight controls and aft gas generator air inlet design - were considered in their limited questionnaire coverage to have a very low degree of risk.

The strong majority of evaluators anticipated relatively minor problems in meeting the program technical objectives and performance goals. More than 97% saw the overall technologies as being either well-established or emerging.

Virtually 100% of the evaluators rated manufacturing technology and facilities as being adequate for the work contemplated, or - at worst - marginal. The same was true of the evaluation of testing methods and facilities. Item 8, Hot Gas Ducting and Valves, was generally rated marginal in these areas.

Also on Item 8, a significant number of evaluators expressed the opinion that materials and components required for development are unavailable and will require long lead times.

Cost and Schedule Risks

Questions 6a, 6b, 7a and 7b were designed to ascertain individuals' opinions in a quantitative form which could be combined into composite evaluations of the various potential risks. The questions asked the evaluators to estimate minimum, maximum and most likely program costs and schedule times associated with the specific risk areas and to indicate level-of-confidence factors for their estimates. It was intended that the method of analytically combining these estimates would depend on the manner in which the minimum - most-likely - maximum estimates were distributed in relation to each other. If, in general, the most-likely values tended to be much closer to one extreme than to the other, it would probably be necessary to use a computerized convolution program for the job of combining, which might consume a substantial amount of time. On the other hand, if the most likely values tended to be close to the midpoint between minimum and maximum it would be quite proper to treat them as normal distributions, in a statistical sense, thereby simplifying the process of computation. A preliminary analysis readily showed that the normal distribution criterion would be valid.

Probable Schedule Impact

The estimates of schedule time required to complete work in the designated risk areas varied considerably on both sides of the preliminary planning estimates. Table II shows the results of the survey, along with the preliminary planning estimates for each of the 16 risk items. To the extent that the opinion survey serves as an indicator, it appears that there is a possibility of some difficulty in meeting the schedule. Even this is not clearly evident, and undoubtedly there is much that can be done through careful planning, to make the best possible use of time in the total program.

CONCLUSIONS

1. The study results indicate that the program risks are manageable and that the total program is feasible from the standpoint of technical risk.
2. Technology and facilities for the manufacture of hot gas ducting and valves are marginal. For all other items, manufacturing technology and facilities are considered low-risk areas.
3. Methods and facilities for testing hot gas ducting and valves are marginal. For all other items, testing methods and facilities are considered low-risk areas.
4. There is some evidence of difficulty in accomplishing the program within the planned time frame. A thorough schedule analysis, using a network and critical path approach would be of value to the program.

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TABLE II

Comparison of Survey Time Schedule Estimates with Preliminary Planning Estimates
for 16 Potential Risk Items* - (All times to nearest month.)

Item No.	Low Speed Mod.			Full-Performance Mod			All-New Aircraft		
	Prel. Pl. Est.	Survey Mean	Survey Diff.	Prel. Pl. Est.	Survey Mean	Survey Diff.	Prel. Pl. Est.	Survey Mean	Survey Diff.
1	24	29	+5	24	29	+5	24	29	+5
2	15	23	+8	15	23	+8	19	25	+6
3	15	26	+11	15	17	+2	19	18	-1
4	24	22	-2	24	21	-3	24	21	-3
5	24	25	+1	24	25	+1	24	27	+3
6	24	25	+1	24	25	+1	24	27	+3
7	24	16	-8	24	16	-8	24	17	-7
8	15	27	+12	15	26	+11	15	27	+12
9	20	20	0	20	20	0	20	20	0
10	24	19	-5	24	19	-5	15	19	+4
11	20	19	-1	20	19	-1	20	19	-1
12	22	19	-3	25	22	-3	30	25	-5
13	15	11	-4	15	11	-4	19	11	-8
14	15	15	0	15	15	0	19	17	-2
15	15	25	+10	15	25	+10	19	27	+8
16	No Est	20	--	No Est	29	--	No Est	32	--

* See Table I for identification of risks with item numbers.